Studies on southern Australian abalone (genus *Haliotis*)
XI. Movement and natural mortality of juveniles

by
S.A. Shepherd (1) and Cecilia Godoy (1,2)

(1) Department of Fisheries
GPO Box 1625
Adelaide, South Australia 5001

(2) Present address: Instituto de Fomento Pesquero,
Casilla 98, Castro, Chiloe, Chile

ABSTRACT

The movement and natural mortality of juvenile *Haliotis scalaris* and *Haliotis laevigata* aged 1 to 3 years were examined in a grid experiment of the Beinssen-Powell design set up on a boulder slope at West Island, South Australia. The mean rate of movement of *H. scalaris* was 0.8 m mth^{-1} and the maximum recorded was 7 m mth^{-1}; the respective rates for *H. laevigata* were a mean of 0.5 m mth^{-1} and a maximum of 1.2 m mth^{-1}. Movement of *H. scalaris* was independent of age and did not vary seasonally. Both species moved directionally east or west, parallel to the shore-line, but there was no significant preference for either direction.

Natural mortality plus tag disappearance rate was 1.1 (s.e. 0.2) for *H. scalaris* and 1.5 (s.e. 0.3) for *H. scalaris* and *H. laevigata* combined; these are equivalent to annual survivals of 34% and 23% respectively. Diver efficiency at finding marked individuals was 0.70 for *H. scalaris* and 0.84 for *H. scalaris* and *H. laevigata* combined.

INTRODUCTION

An understanding of recruitment variability is a central problem in the dynamics of exploited abalone populations. Studies of settlement of abalone (Shepherd & Turner 1985, Shepherd *et al.* 1985, 1988) have shown high variability between years in settlement strength but there is fundamental uncertainty whether subsequent recruitment of abalone to the fishery is determined primarily by settlement strength or by a variable juvenile mortality. Because abalone are mobile, experiments

designed to measure their natural mortality must take into account the movement of juveniles.

This paper describes a pilot experiment to measure simultaneously the movement and natural mortality rate of cryptic juvenile abalone in a boulder habitat where juveniles are accessible only by overturning the boulders. The study was carried out at West Island, South Australia (35⁰ 37' S; 138⁰ 35' E) where long term studies on the dynamics of abalone populations are in progress. Two species of abalone occur in this habitat: *Haliotis laevigata* Donovan an exploited species and *Haliotis scalaris* Leach a small non-commercial species.

The experimental design of Beinssen & Powell (1979) was modified and used to measure the movement and natural mortality of marked individuals.

METHODS AND MATERIALS

Field

The north shore of West Island is a slope covered by rounded boulders of 30-40 cm greater diameter and 20-30 cm lesser diameter. The study site extends for about 60 m along the shore and is bounded on the seaward side by bare sand and seagrass beds. Unsuitable habitat prevents the movement of abalone out of the study site at each end.

A chain grid measuring 9 m x 4 m and divided internally at 1 m intervals was placed among the boulders at 4-5 m depth (Fig 1). On four occasions the ten central squares in the grid were searched and juvenile *H. scalaris* and *H. laevigata* between 15 and 40 mm length were taken to the surface and marked with plastic numbered tags glued to the spire of the shell with cyanoacrylate (superglue). Due to poor recruitment very few *H. laevigata* were found for marking after the first release. Marked individuals were held overnight on the seabed in containers in order to detect tagging mortality and then replaced in the grid in one of the 3 categories of replacement squares and the square of replacement noted. Care was taken not to artificially increase the density of abalone naturally present (see Shepherd 1986). On the date of each release and on 2 occasions 3-4 months after the final release the grid was searched for marked abalone and the number of the square occupied by a marked individual was noted. Subsequently on 5 occasions until September 1988 stratified random searches for marked individuals (involving a total of 25 hours searching time) were conducted throughout the whole study site over 60 m of shore-line in order to obtain additional data on movement.

Analysis

The net movement and direction of marked individuals within the grid were calculated by using Pythagorean geometry. The frequency of angular data in each of four quadrants of the circle was counted and a χ^2 test used to determine whether observed frequencies differed significantly from those expected under randomness. Mean vectors, axes, confidence intervals and other circular statistics were calculated with formulae given by Batschelet (1981). The marked abalone were aged in accordance with age-length curves given by Shepherd (1988) and Shepherd *et al.* (1988).

The survival of marked abalone in the grid was calculated according to the method of Beinssen & Powell (1979) where the reader is referred for more detail.

Briefly, the method uses the movement of abalone recorded within the grid during the study to estimate the proportion of marked abalone that do not move outside the grid, and this value is used to weight p given below. In this study (see Fig. 1) there were 18 possible types of movement, k, of abalone (up to 6 squares east or west and 2 squares north or south) within the grid from the 3 kinds of release square, that did not take an abalone out of the grid. The probability, p, of recapture of a marked abalone in the grid is given by the formula:

$$p = \sum_{k=1}^{18} \frac{C_k N_k}{P_k}$$

when N_k is the number of movements of type k, P_k is the probability of a movement of type k and

$$C_k = \frac{1}{\sum_{j=1}^{3} n_j A_{jk}}$$

Here n_j is the number of marked abalone released in the jth square, and A_{jk} is the fraction of movements not taking the abalone out of the grid. Beinssen and Powell (1979) assumed that $\sum P_k = 1$ i.e. that there were no other types of movement other than those observed in the grid. In this study there were data on the movement of abalone well beyond the boundaries of the grid that enabled us to give estimates of $\sum P_k$ for each release (see results).

The probability of recapture of abalone from each of the four releases was calculated on the assumptions that :

(1) abalone would not move out of the grid in a northerly direction onto sandy bottom, and

(2) abalone would not move in a southerly direction out of the grid. This is shallow water habitat where these abalone species are not found.

A formula for the calculation of the variance of p is given by Beinssen & Powell (1979). Where there are several releases Beinssen & Powell (1979) showed that:

$$\ln p = \ln (x_1 x_2) - Xt$$

where t is the period at liberty, x_1 is the probability that an abalone is not lost by tagging mortality and x_2 is the efficiency of the diver in finding marked abalone. A regression of ln p against t gives a straight line of slope -X which is the coefficient of reduction of marked abalone from natural mortality and loss of marks. The y intercept is the natural logarithm of $x_1 x_2$.

RESULTS

Movement rate

In all 111 *H. scalaris* and 25 *H. laevigata* were released in the grid and there were 81 subsequent sightings with periods at liberty ranging from 3 to 13 months.

First we examined whether there was a difference in the rate of movement of *H. scalaris* by age. There were 14 sightings of individuals aged 1+ years, 15 sightings of those aged 2+ years and 6 sightings of those aged 3+ years. The null hypothesis that the frequency distribution of movement rates did not differ between age classes was

tested and accepted ($\chi^2 = 0.27$; p>0.05 n.s.). Next we examined whether there were seasonal differences in the movement rate of *H. scalaris*. For vthis analysis we compared two 6-month periods (5 Nov - 5 June and 5 June - 5 Nov) which correspond roughly with the warm and cool periods of the year, with 23 and 15 data points respectively available for comparison. The mean movement rate was 0.65 m mth-¹ in the former period and 0.41 m mth-¹ in the latter; they did not differ significantly (t = 1.06; p>0.05 n.s.).

Frequency distributions of net distances moved by marked *H. scalaris* for varying periods at liberty are shown in Fig. 2. The median distance moved ranges from 1.5 m after 3 months to 3.5 m after 12 months; the mean distances moved range from 2.5 m to 4.2 m for the same periods of time. The maximum distance moved was 22 m. The number of recoveries declines sharply with time due to dispersion and mortality of marked abalone.

Data on movement rates of *H. laevigata* were too few for analysis in the same way as for *H. scalaris*. However, the mean distance moved was 0.50 m mth-¹ (s.e. 0.11 m) for 15 individuals and the maximum distance moved was 4 m. Frequency distributions of the movement rates for all data available for both species were compared and found not to be significantly different ($\chi^2 = 5.4$; p>0.2) from each other.

Direction of movement

The net direction of movement of 36 *H. scalaris* and 15 *H. laevigata* is shown in Fig. 3. Most individuals moved either east or west along the longitudinal grid axis, thus showing bimodality in direction. The angles were accordingly doubled and the Rayleigh statistic used to test the null hypothesis that direction was random. The mean vectors (r_2) were 0.59 for *H. scalaris* and 0.47 for *H. laevigata* and the null hypotheses rejected in each case (P<0.001 and P<0.03 respectively). The mean axes (ϕ) were 7.4⁰ for *H. scalaris* and 4.2⁰ for *H. laevigata* (Fig 3) deviation from the longitudinal axis (i.e. parallel to shore) and the 95% confidence angles were 23⁰ and 49⁰ respectively. Because these angles include the direction of the longitudinal axis it was concluded that the mean direction of movement of both species did not differ significantly from that of the longitudinal axis. Fifteen *H. scalaris* moved in an easterly direction along this axis (+/-45⁰) and 18 in the opposite westerly direction; for *H. laevigata* the figures were 6 and 7 respectively. These numbers did not differ significantly from the expectation of equality of numbers moving in each opposing sector ($\chi^2 = 0.03$ and 0.08; n.s.) and it was concluded that there was no significant trend for either species to move either east or west.

Natural mortality and diver efficiency

Details of the numbers and species of marked abalone released in the grid, the number of recaptures, the period at liberty, values of Σ P_k, and the calculated values of p are given in Table 1. Values of Σ P_k, the probability that marked abalone do not move out of the grid, were calculated directly for each release from the movement data summarised in Fig. 2. For example, Σ Pk for the 4th release of *H. scalaris* was 39/40, because only one marked abalone moved from a release square right out of the grid. Plots of p against time are shown in Fig. 4. The regression ln p against time gave a value of 1.08 (s.e. 0.19) for the natural mortality plus tag shedding rate of *H. scalaris*, and 1.48 (s.e. 0.27) for *H. scalaris* and *H. laevigata* combined, (there being insufficient data to calculate a mortality rate for *H. laevigata* alone). These values are equivalent to an annual survival of 34% and 23% respectively if no tags were shed. A pilot experiment to estimate the tag

shedding rate (a return of 10 double tags) showed no loss of tags. However, 2 individuals at liberty for a year were found with the tag overgrown with bryozoans. Hence an experiment is needed to estimate the rate of disappearance of tags from fouling.

TABLE 1 - Release Recapture Data for 4 releases in the Grid; p is the probability of recapture.

		NUMBER OF RELEASES				NUMBER OF RECAPTURES				
						Days at liberty	H. scalaris		H. scalaris and H. laevigata	
Release	Date	Haliotis scalaris	Haliotis laevigata	Haliotis scalaris	Haliotis laevigata	$\sum P_k$	p (s.e.)	$\sum P_k$	p (s.e.)	
1	5.11.86	15	14	2	2	375	0.83	0.21 (0.09)	0.89	0.18 (0.04)
2	5. 2.87	28	5	7	1	283	0.90	0.34 (0.03)	0.92	0.30 (0.03)
3	2. 6.87	25	1	8	0	166	0.90	0.39 (0.03)	0.94	0.36 (0.04)
4	4. 8.87	42	2	14	2	103	0.98	0.52 (0.02)	0.98	0.61 (0.03)

The y-intercept for *H. scalaris* was 0.70 and for both species 0.84. These represent the product of x_1, the tagging mortality and x_2 the efficiency of divers at finding marked abalone. Tagging mortality is not known but is thought to be low. The retention of marked animals overnight in a cage on the seabed before placement in the grid enabled us to examine and discard animals only feebly attached to the substratum (usually 5-10%). The location of replacement in the grid was re-examined within a month for empty tagged shells. Only two were discovered, so we provisionally estimate tagging mortality as 2/136 i.e. 1.5%. Hence diver efficiency, x_2 is 0.71 for *H. scalaris* and 0.85 for both species. However, the final census when tagged animals were recovered was carried out on 2 occasions. On the first occasion there were 25 recaptures and on the second there were a further 11 recaptures. This indicates that diver efficiency per search is less, and if all marked abalone in the grid were recaptured, would be 50% and 59% respectively per search.

DISCUSSION

The Beinssen-Powell experimental design is an ingenious way of measuring simultaneously the mobility and natural mortality of a sedentary animal. The successful outcome of the experiment depends on the correct choice of scale of the grid according to the pattern and extent of movement that occurs. The method assumes that net movement is random and consistent over time, although departures from these assumptions could be incorporated in the model. This study establishes the applicability of the method to juvenile abalone and provides useful information on their long-term dispersal and natural mortality; it also provides estimates of diver efficiency which are useful in designing further experiments to measure natural mortality.

There are no other known published studies on the movement of juvenile abalone. However, Clavier & Richard (1985) recorded a general off-shore movement of juvenile abalone which settled close to shore. In addition, some incidental information on juvenile dispersal is to be found in studies of the release into the wild of hatchery-reared seed (Tegner & Butler 1985, Ebert & Ebert 1988). Both studies recorded dispersal of a similar scale to that described here.

North

Sandy substratum

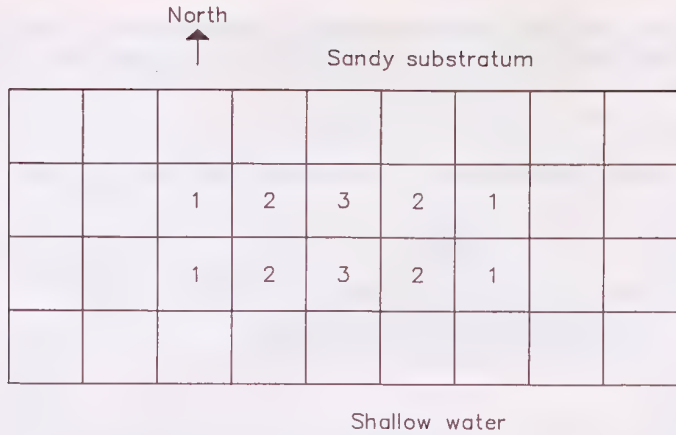|								
		1	2	3	2	1		
		1	2	3	2	1		

Shallow water

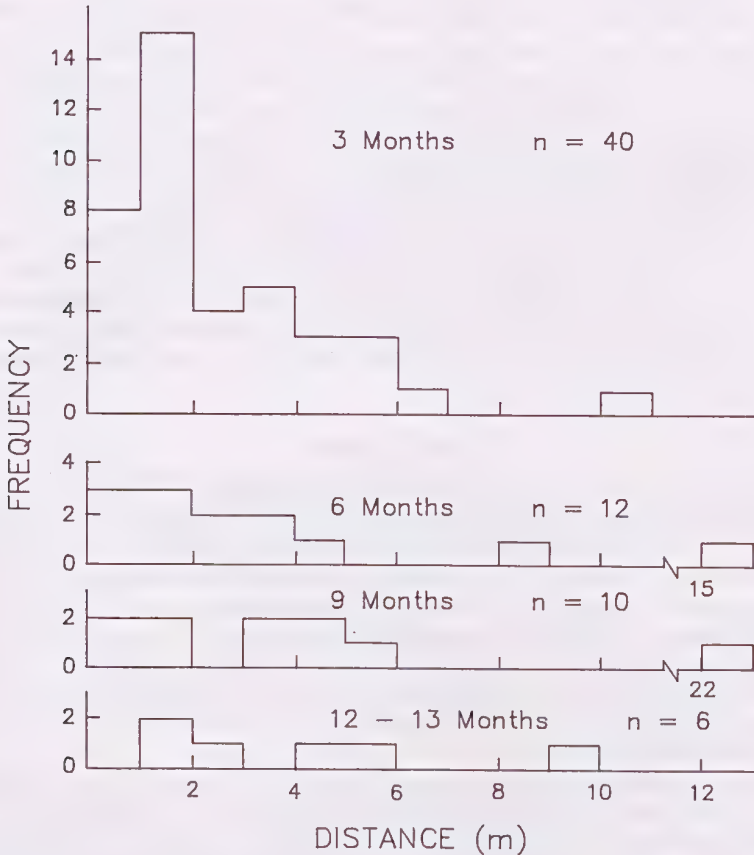Figure 1:   Layout of grid on northern shore of West Island with 3 categories of released squares.

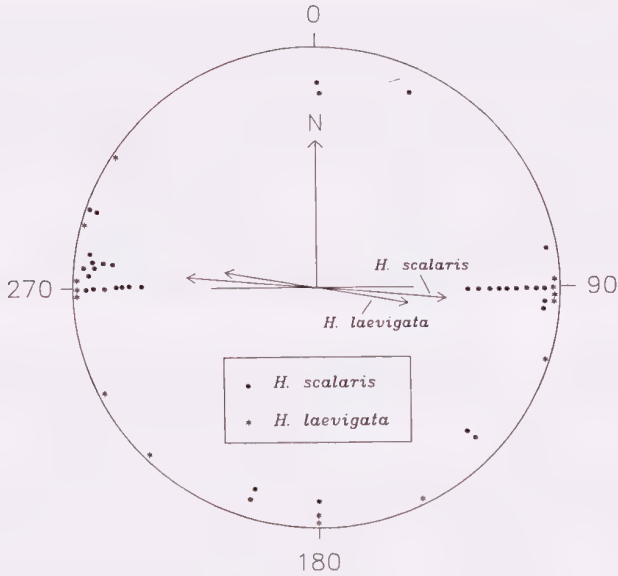Figure 2:   Frequency distribution of net distances moved by juvenile *H. scalaris* in and beyond the grid.

Figure 3: Net direction of movement of *H. scalaris* and *H. laevigata* in the grid. The mean axes of deviation from the longitudinal (east-west axis) of the grid are shown for both species.
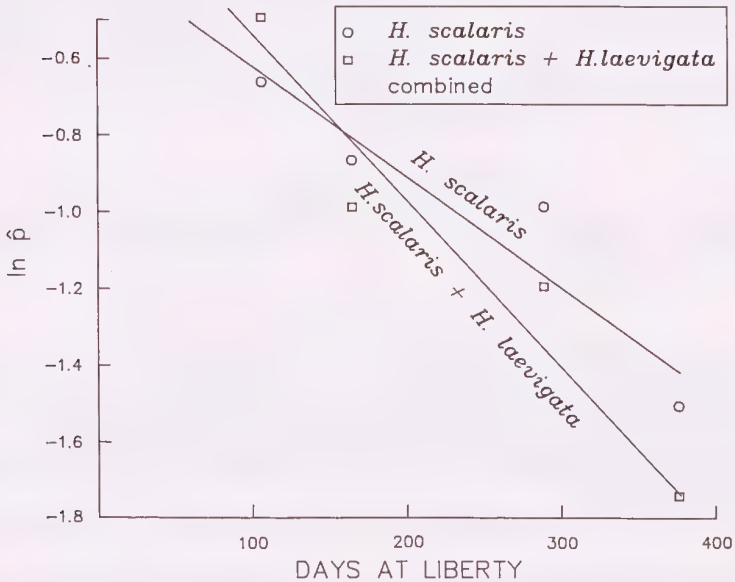

Figure 4: Plot of ln p against number of days at liberty, with linear regressions for *H. scalaris* and both species combined.

This study has not taken into account the effect of disturbance on the movement of juveniles. It is possible that disturbance from divers overturning boulders during searches, despite the care that was taken, increases movement and even mortality. Clavier & Richard (1985) experimentally compared the effect of strong and weak habitat disturbance on the movement of *Haliotis tuberculata*. They reported no significant difference in distance moved between the two treatments (after excluding those that djd not move in either treatment). However, re-examination of their data showed that significantly more individuals moved when the habitat was strongly disturbed ($\chi_3^2 = 25.5$, P <0.001). For this test we compared the frequency distribution for movement of each treatment. Thus it is likely that disturbance will induce some initial movement, if not movement over greater distances.

The survival rates recorded here are of limited value for two reasons. First, there are relatively few recoveries, and secondly the estimates of $\sum P_k$ may be subject to some bias. Because more time was spent searching in the grid than outside it, it is possible that we may have under-estimated the numbers which moved out of the grid altogether. The bias caused by this under-estimate means that the estimate of the natural mortality rate may be too high. A larger plot size would reduce this bias, but there are obvious practical limitations on the size of the plot that can be used.

The only other known study of juvenile abalone survival among wild stocks is that of Day & Leorke (1986). In studies of *H. rubra* they recorded about 50% survival a year for individuals 20-40 mm long and about 33% survival for those over 40 mm. However, there are numerous studies of the survival öf abalone seed transplants onto natural reefs. These show survival rates of between 20 and 50% a year (Momma *et al.* 1980, Kojima 1981, Miyamoto *et al.* 1982, Saito 1984, Tegner & Butler 1985). The values recorded in this paper are in the same range as other studies and tend to confirm the picture that only a small percentage of newly settled abalone will survive the juvenile phase of the life history. The estimates of diver efficiency are similar to those found by Clavier & Richard (1985) and are useful in independent experiments to measure survival that depend on the diver measuring changes in density of juvenile abalone over time.

ACKNOWLEDGEMENTS

LITERATURE CITED

Batschelet, E., 1981. Circular statistics in biology. Academic Press, London.

Beinssen, C. & Powell, D. 1979. Measurement of natural mortality in a population of blacklip abalone *Notohaliotis ruber*. Rapp. P.V. Reun Cons. Int. Explor. Mer, 175, pp. 23-26.

Clavier, J. & Richard, O. 1985. Etudes sur les ormeaux dans la region de Saint-Malo: rapport de synthèse et bibliographie indexée 275pp. Assoc. pour la Mise en Valeur du Littoral de la Côte d'Emeraude, Saint-Malo.

Day, R.W. & Leorke, A.E. 1986. Abalone catches - what factors affect them. Aust. Fisheries 45(10): 32-36.

Ebert, T.B. & Ebert, E.E. 1988. An innovative technique for seeding abalone and preliminary results of laboratory and field trials. Calif. Fish and Game 74:68-81.

Kojima, H. 1981. Mortality of young Japanese black abalone *Haliotis discus discus* after transplantation. Bull. Japan Soc. Sci. Fish. 47: 151-159.

Miyamoto, T., Saito, K., Motoyo, S., & Kawamura, K. 1982. Experimental studies on the release of the cultured seeds of abalone, *Haliotis discus hannai* Ino in Oshoro Bay, Hokkaido. Sci. Repts. Hokkaido Fisheries Experimental Station, No. 24: 59-89. (English abstract, figures and tables).

Momma, H., Kobayashi, K., Kato, T., Sasaki, Y., Sakamoto, T., & Murata, H. 1980. On the artificial propagation method of abalone and its effects on rocky shore. I. Remaining ratio of the artificial seed abalone (*Haliotis discus hannai* Ino) on latticed artificial reefs. Suisan Zoshoku (The Aquaculture) 28: 59-65. (Translation by Mottet, M., State of Washington, Department of Fisheries.)

Saito, K. 1984. Ocean ranching of abalones and scallops in northern Japan. Aquaculture 39: 361-373.

Shepherd, S.A. 1986. Movement of the southern Australian abalone *Haliotis laevigata* in relation to crevice abundance. Aust. J. Ecol. 11: 295-302.

Shepherd, S.A. 1988. Studies on southern Australian abalone (genus *Haliotis*). VIII. Growth of juvenile *H. laevigata* Aust. J. Mar. Freshw. Res. 39: 177-183.

Shepherd, S.A., Clarkson, P.S. & Turner, J.A. 1985. Studies on southern Australian abalone (genus *Haliotis*). V. Spawning, settlement and early growth of *H. scalaris*. Trans. R. Soc. S. Aust. 109: 61-62.

Shepherd, S.A., Mower, A.G.J. & Hill, K. 1988. Studies on southern Australian abalone (genus *Haliotis*). IX. Growth of *H. scalaris*. Trans R. Soc. Aust. 112: 93-95.

Shepherd, S.A. & Turner J.A. 1985. Studies on southern Australian abalone (genus *Haliotis*). VI. Habitat preference, abundance and predators of juveniles. J. Exp. Mar. Biol. Ecol. 93: 285-298.

Tegner, M. J. & Butler, R.A. 1985. The survival and mortality of seeded and native red abalones, *Haliotis rufescens*, on the Palos Verdes Peninsula. Calif. Fish. & Game. 71: 150-163.